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(54) **NESTED SPECULATIVE REGIONS FOR A SYNCHRONIZATION FACILITY**

(71) Applicant: **Advanced Micro Devices, Inc.**, Sunnyvale, CA (US)

(72) Inventors: **Stephan Diestelhorst**, Dresden (DE); **Martin Pohlack**, Dresden (DE); **Michael Hohmuth**, Dresden (DE); **David Christie**, Austin, TX (US); **Luke Yen**, Ayer, MA (US)

(73) Assignee: **Advanced Micro Devices, Inc.**, Sunnyvale, CA (US)

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(51) **Int. Cl.**
G06F 9/38 (2006.01)
G06F 9/52 (2006.01)

(52) **U.S. Cl.**
CPC ***G06F 9/3842*** (2013.01); ***G06F 9/3857*** (2013.01); ***G06F 9/3861*** (2013.01); ***G06F 9/528*** (2013.01)

(58) **Field of Classification Search**
None
See application file for complete search history.

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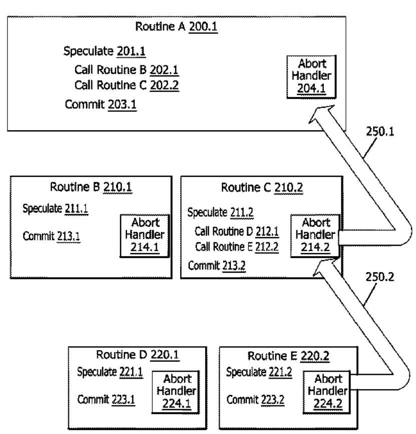
Primary Examiner — William B Partridge
(74) *Attorney, Agent, or Firm* — Volpe and Koenig, P.C.

(57) **ABSTRACT**

An apparatus, computer readable medium, and method of performing nested speculative regions are presented. The method includes responding to entering a speculative region by storing link information to an abort handler and responding to a commit command by removing link information from the abort handler. The method may include storing link information to the abort handler associated with the speculative region. When the speculative region is nested, the method may include storing link information to an abort handler associated with a previous speculative region. Removing link information may include removing link information from the abort handler associated with the corresponding speculative region. The method may include restoring link information to the abort handler associated with a previous speculative region. Responding to an abort command may include running the abort handler associated with the aborted speculative region. The method may include running the abort handler of each previous speculative region.

13 Claims, 8 Drawing Sheets



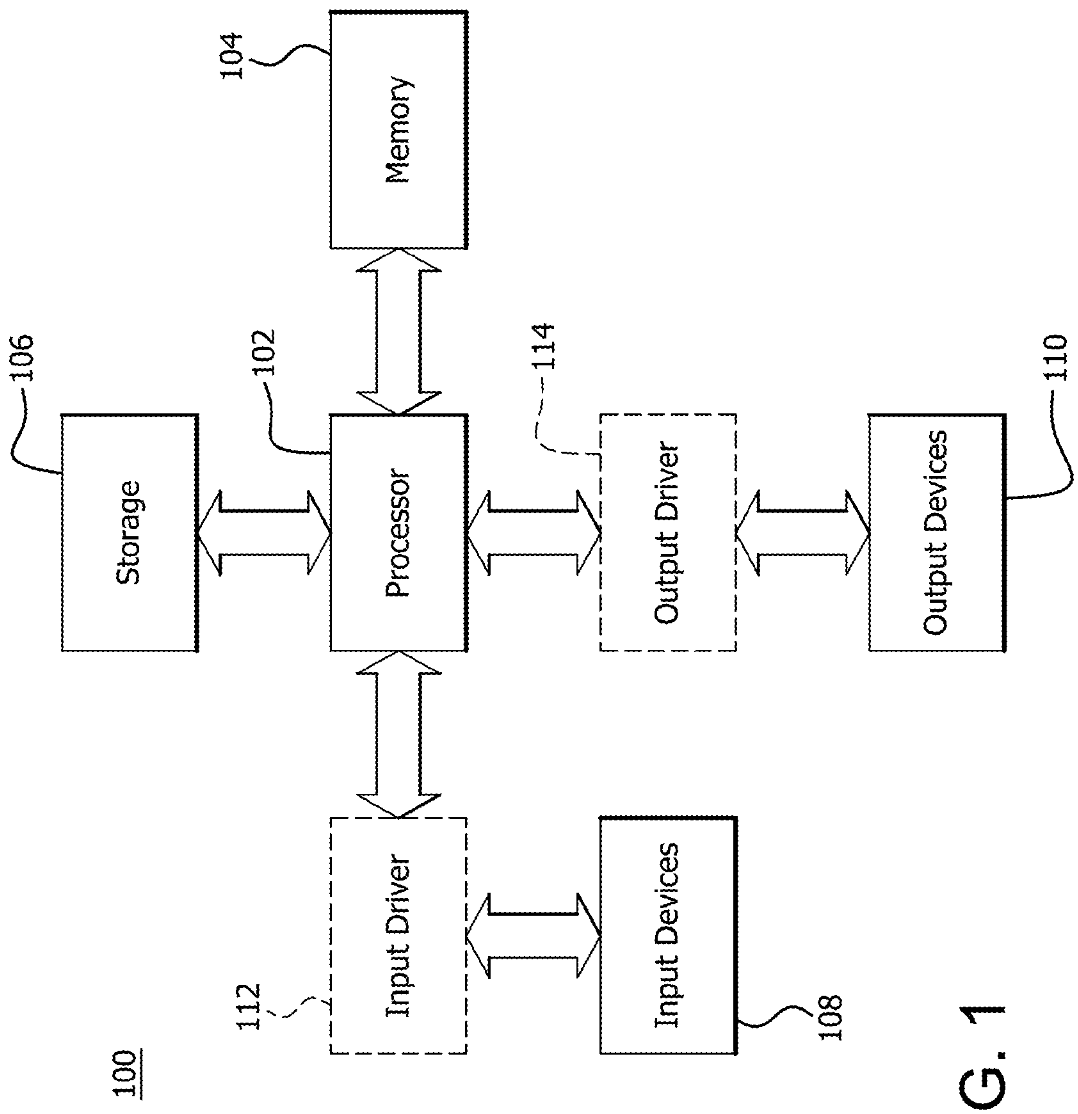

100
Storage
106
Processor
102
Memory
104
Output Driver
114
Output Devices
110
Input Driver
112
Input Devices
108

FIG. 1

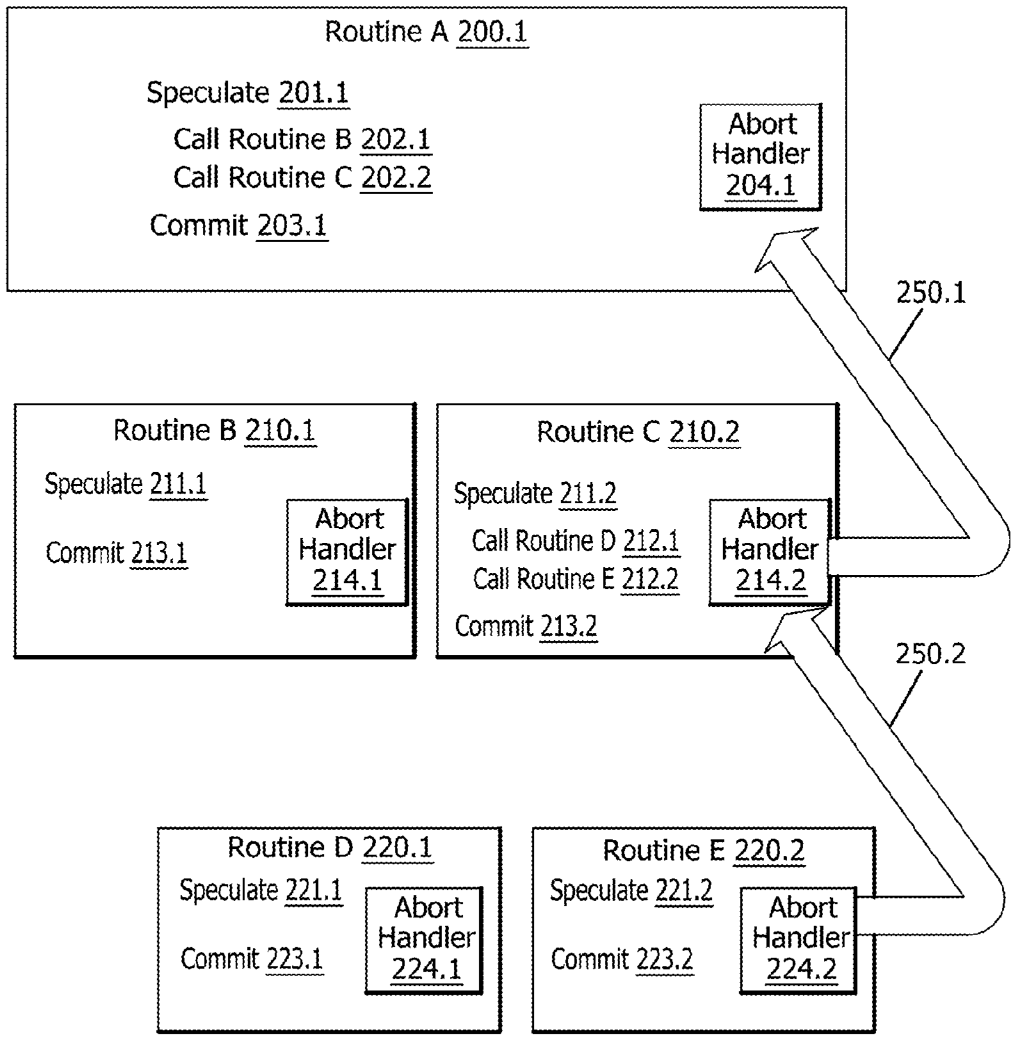

Routine A 200.1
Speculate 201.1
Call Routine B 202.1
Call Routine C 202.2
Commit 203.1
Abort Handler 204.1
250.1
Routine B 210.1
Speculate 211.1
Commit 213.1
Abort Handler 214.1
Routine C 210.2
Speculate 211.2
Call Routine D 212.1
Call Routine E 212.2
Commit 213.2
Abort Handler 214.2
250.2
Routine D 220.1
Speculate 221.1
Commit 223.1
Abort Handler 224.1
Routine E 220.2
Speculate 221.2
Commit 223.2
Abort Handler 224.2

FIG. 2

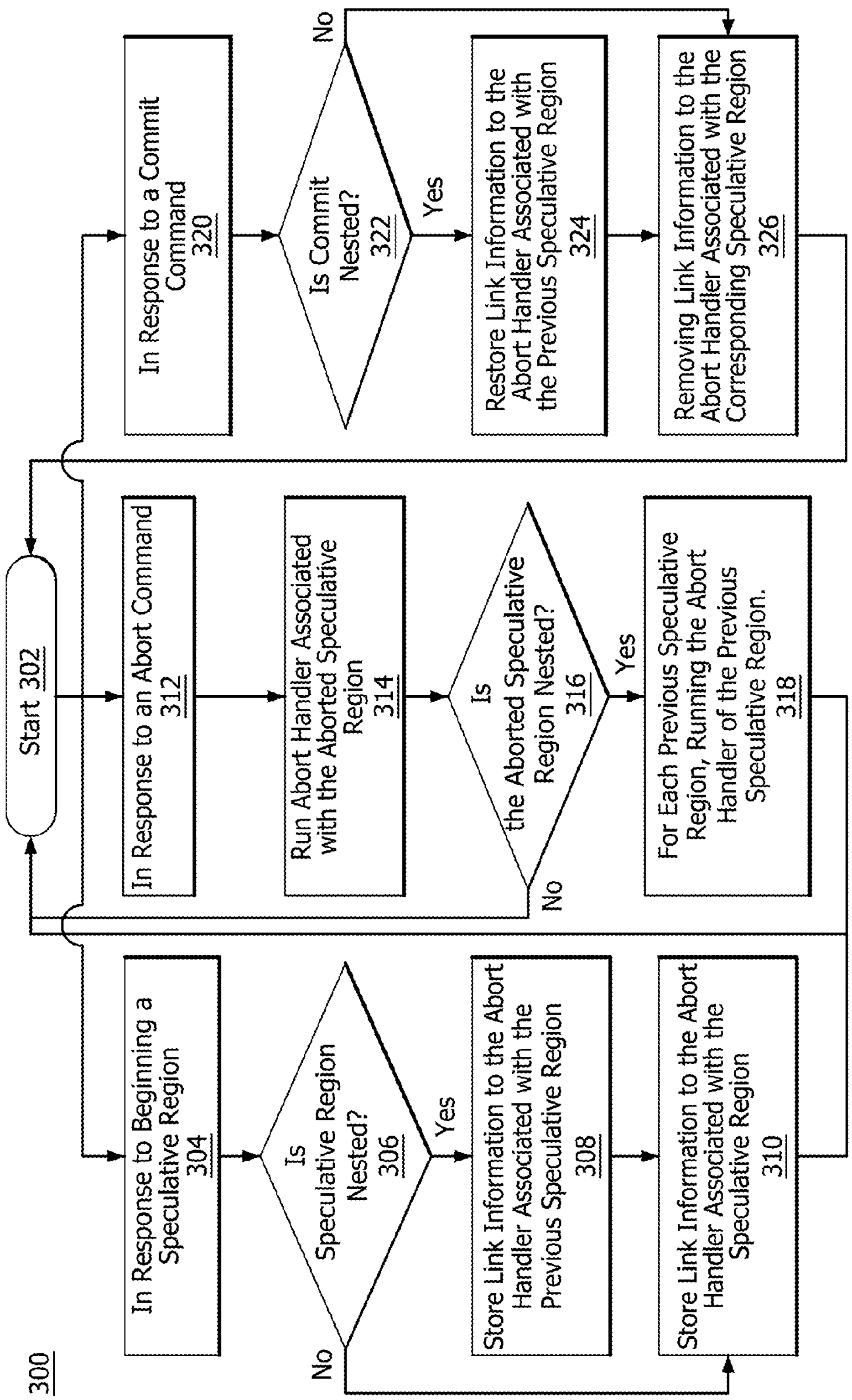

300
Start 302
In Response to Beginning a Speculative Region 304
Is Speculative Region Nested? 306
Yes
No
Store Link Information to the Abort Handler Associated with the Previous Speculative Region 308
Store Link Information to the Abort Handler Associated with the Speculative Region 310
In Response to an Abort Command 312
Run Abort Handler Associated with the Aborted Speculative Region 314
Is the Aborted Speculative Region Nested? 316
Yes
No
For Each Previous Speculative Region, Running the Abort Handler of the Previous Speculative Region. 318
In Response to a Commit Command 320
Is Commit Nested? 322
Yes
No
Restore Link Information to the Abort Handler Associated with the Previous Speculative Region 324
Removing Link Information to the Abort Handler Associated with the Corresponding Speculative Region 326

FIG. 3

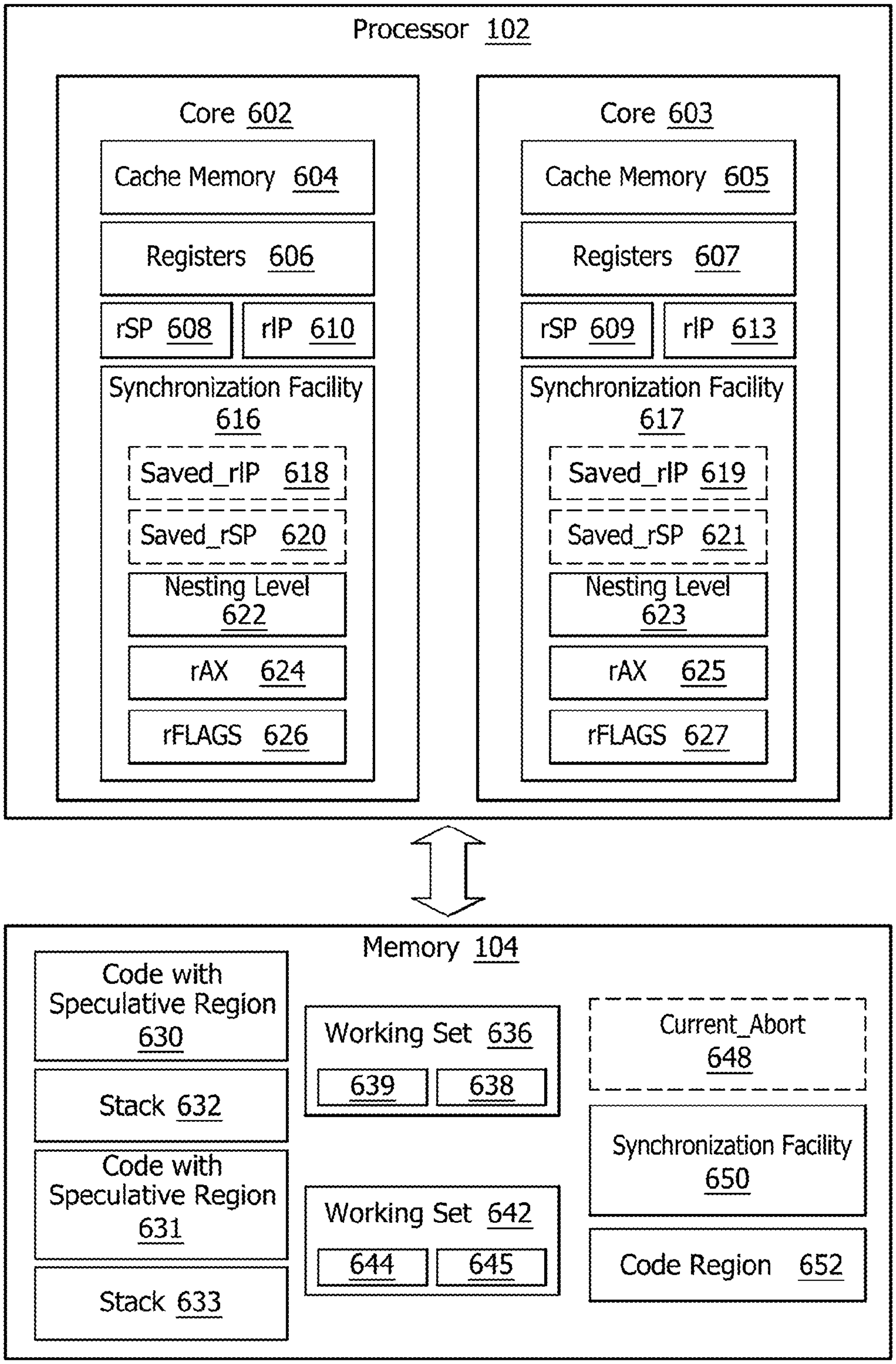

Processor 102
Core 602
Cache Memory 604
Registers 606
rSP 608
rIP 610
Synchronization Facility 616
Saved_rIP 618
Saved_rSP 620
Nesting Level 622
rAX 624
rFLAGS 626
Core 603
Cache Memory 605
Registers 607
rSP 609
rIP 613
Synchronization Facility 617
Saved_rIP 619
Saved_rSP 621
Nesting Level 623
rAX 625
rFLAGS 627
Memory 104
Code with Speculative Region 630
Stack 632
Code with Speculative Region 631
Stack 633
Working Set 636
639
638
Working Set 642
644
645
Current_Abort 648
Synchronization Facility 650
Code Region 652

FIG. 4

502

Non-Nested SPECULATE

(a) Store the instruction pointer for the next instruction;

(b) Stores the stack pointer;

(c) Adjust nesting level.

504

Nested SPECULATE

(a) Save the stored instruction pointer and the stored stack pointer;

(b) Store the instruction pointer and stack pointer like the non-nested SPECULATE;

(c) Adjust nesting level.

506

Nested COMMIT

(a) Restores the values for the saved instruction pointer and the saved stack pointer

(b) Adjust nesting level.

508

Non-Nested COMMIT

(a) Adjust nesting level.

500

FIG. 5

430 400 630

```
401: Retry:
402:         SPECULATE
403:         JNZ Abort_Handler
404:         Access memory locations 638, 639
405:               call nested SPECULATE
406:         Access memory locations 638, 639
407:         COMMIT
408:          END

409: Abort_Handler:
410:         // Clean up modifications made by this Speculative
411:         // Region (registers, non-speculative modification)
412:         // Keep statistics about an abort of this speculative region
413:         // Test if we need further unwinding (rAX)
414:         TEST rAX, ASF_NEST_MASK
415:         JZ Done
416:         // Unwind the stack of abort handlers in software
417:         SUB rAX, 1  << ASF_NEST_START // Reduce nesting count
418:         POP rDI    // get outer Abort_rIP or saved instruction pointer
419:         POP rSP   // get outer Abort_rSP or saved stack pointer
420:         JMP [rDI]  // branch to outer abort handler
421:         //  --- code for unwinding abort handlers in software
422: Done:
423:         // Normal handling of non-nested aborts, e.g.
424:         JMP Retry
```

FIG. 6A

430 400 631

```
450:            -------------Nested Speculative Region -------------
451:  Nested_Speculate
452:            SPECULATE
453:            JNZ Nested_abort
454:            Access memory locations 644, 645
455:            COMMIT
456:            Return
457:  Nested_abort:
458:            // Clean up modifications made by Nested Speculative
459:            // Region (registers, non-speculative modification)
460:            // Keep statistics about an abort of this speculative region
461:            // Test if we need further unwinding (rAX)
462:            TEST rAX, ASF_NEST_MASK
463:            JZ Nest_Done
464:            // Unwind the stack of abort handlers in software
465:            SUB rAX, 1  << ASF_NEST_START // Reduce nesting count
466:            POP rDI    // get outer Abort_rIP or saved instruction pointer
467:            POP rSP    // get outer Abort_rSP or saved stack pointer
468:            JMP [rDI]  // branch to outer abort handler
470:  Nest_Done:
471:            // Normal handling of non-nested aborts, e.g.
472:            JMP Nested_Speculate
```

FIG. 6B

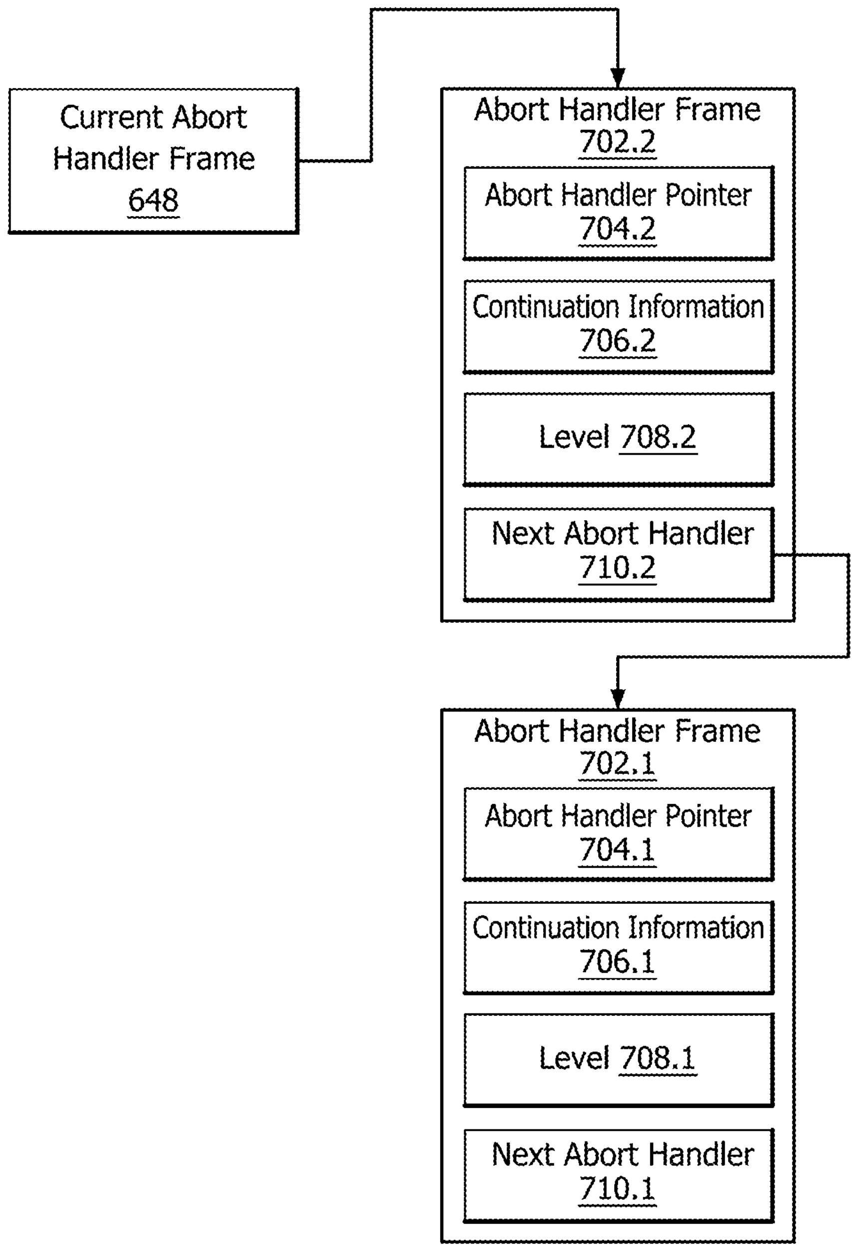

Current Abort Handler Frame 648
Abort Handler Frame 702.2
Abort Handler Pointer 704.2
Continuation Information 706.2
Level 708.2
Next Abort Handler 710.2
Abort Handler Frame 702.1
Abort Handler Pointer 704.1
Continuation Information 706.1
Level 708.1
Next Abort Handler 710.1

FIG. 7

NESTED SPECULATIVE REGIONS FOR A SYNCHRONIZATION FACILITY

TECHNICAL FIELD

The disclosed embodiments are generally directed to nested speculative regions, and in particular, to nested speculative regions for a synchronization facility.

BACKGROUND

Many modern computers have multiple processors or cores that share memory. One challenge with multiple processors is how to permit the multiple processors to share memory.

A synchronization facility allows modification of multiple memory locations (often called a "working set") by a single region of instructions (often called a "speculative region") executed by a single processor. The synchronization facility allows a speculative region to access the working set of memory locations, while watching the working set to detect accesses from other speculative regions being executed by other processors.

If another processor accesses a memory location of the working set, then the synchronization facility determines that there is a conflict and aborts one of the speculative regions. This enables the cores to share the memory without interfering with one another.

Therefore, there is a need in the art for an apparatus and method of performing nested speculative regions for a synchronization facility.

SUMMARY OF EMBODIMENTS

Some embodiments provide a method of performing nested speculative regions. The method includes responding to entering a speculative region by storing link information to an abort handler and responding to a commit command by removing link information from the abort handler. The method may include storing link information to the abort handler associated with the speculative region. When the speculative region is nested, the method may include storing link information to an abort handler associated with a previous speculative region. Removing link information may include removing link information from the abort handler associated with the corresponding speculative region. The method may include restoring link information to the abort handler associated with a previous speculative region. Responding to an abort command may include running the abort handler associated with the aborted speculative region. The method may include running the abort handler of each previous speculative region.

Some embodiments provide an apparatus for performing nested speculative regions. The apparatus includes two or more processors where each processor may include an instruction pointer (IP) register, a stack pointer (SP) register, a saved_rIP register, and a saved_rSP register. The apparatus may include a memory comprising memory locations. Each processor of the two or more processors may be configured to respond to entering a speculative region by storing link information to an abort handler associated with the speculative region, and if the speculative region is nested, then storing link information to an abort handler associated with a previous speculative region. Each processor of the two or more processors may respond to a commit command by removing link information to the abort handler associated with the corresponding speculative region, and if the commit

is nested, then restoring link information to the abort handler associated with the previous speculative region. Each processor of the two or more processors may respond to an abort command by running the abort handler associated with the aborted speculative region, and if the aborted speculative region is nested, then for each previous speculative region, running the abort handler of the previous speculative region.

BRIEF DESCRIPTION OF THE DRAWINGS

A more detailed understanding may be had from the following description, given by way of example in conjunction with the accompanying drawings wherein:

FIG. **1** is a block diagram of an example device in which one or more disclosed embodiments may be implemented;

FIG. **2** schematically illustrates an example of the operation of an embodiment of an apparatus and method for nested speculative regions for a synchronization facility, in accordance with some embodiments;

FIG. **3** schematically illustrates an embodiment of a method for performing nested speculative regions, in accordance with some embodiments;

FIG. **4** schematically illustrates an example of an embodiment of an apparatus for nested speculative regions for a synchronization facility, in accordance with some embodiments;

FIG. **5** illustrates examples of synchronization facility commands speculate, nested speculate, commit, and nested commit commands, in accordance with some embodiments;

FIGS. **6**A and **6**B schematically illustrates code with speculative regions, in accordance with some embodiments; and

FIG. **7** illustrates an example of a synchronization facility for nested speculative regions, in accordance with some embodiments.

DETAILED DESCRIPTION OF EMBODIMENTS

FIG. **1** is a block diagram of an example device **100** in which one or more disclosed embodiments may be implemented. The device **100** may include, for example, a computer, a gaming device, a handheld device, a set-top box, a television, a mobile phone, or a tablet computer. The device **100** includes a processor **102**, a memory **104**, a storage **106**, one or more input devices **108**, and one or more output devices **110**. The device **100** may also optionally include an input driver **112** and an output driver **114**. It is understood that the device **100** may include additional components not shown in FIG. **1**.

The processor **102** may include a central processing unit (CPU), a graphics processing unit (GPU), a CPU and GPU located on the same die, or one or more processor cores, wherein each processor core may be a CPU or a GPU. The CPU may include a synchronization facility for synchronizing memory access among multiple processors. The memory **104** may be located on the same die as the processor **102**, or may be located separately from the processor **102**. The memory **104** may include a volatile or non-volatile memory, for example, random access memory (RAM), dynamic RAM, or a cache. The memory **104** may include a synchronization facility.

The storage **106** may include a fixed or removable storage, for example, a hard disk drive, a solid state drive, an optical disk, or a flash drive. The input devices **108** may include a keyboard, a keypad, a touch screen, a touch pad, a detector, a microphone, an accelerometer, a gyroscope, a biometric scanner, or a network connection (e.g., a wireless local area network card for transmission and/or reception of wireless IEEE 802 signals). The output devices **110** may include a display, a speaker, a printer, a haptic feedback device, one or more lights, an antenna, or a network connection (e.g., a wireless local area network card for transmission and/or reception of wireless IEEE 802 signals).

The input driver **112** communicates with the processor **102** and the input devices **108**, and permits the processor **102** to receive input from the input devices **108**. The output driver **114** communicates with the processor **102** and the output devices **110**, and permits the processor **102** to send output to the output devices **110**. It is noted that the input driver **112** and the output driver **114** are optional components, and that the device **100** will operate in the same manner if the input driver **112** and the output driver **114** are not present.

FIG. **2** schematically illustrates an example of the operation of an embodiment of an apparatus and method for nested speculative regions for a synchronization facility. Illustrated in FIG. **2** are routines **200.1**, **210.1**, **210.2**, **220.1**, and **220.2** and the corresponding abort handlers **204.1**, **214.1**, **214.2**, **224.1**, and **224.2** and links **250.1** and **250.2** and. Routines **200.1**, **210.1**, **210.2**, **220.1**, and **220.2** may be software implement routines that use a synchronization facility and are being executed by a processor **102**. Routines **210.2** and **220.2** are nested routines since they were called by another routine **200.1**, and **210.2**, respectfully. Abort handlers **204.1**, **214.2**, **224.2**, handle cleanup for a routine **200.1**, **210.2**, **220.2** when a speculative region has been aborted due to a conflict with another processor. Return arrows **250.2**, **250.1** indicate the sequence in which abort handlers **224.2**, **214.2**, and **204.1** are executed.

FIG. **3** schematically illustrates an embodiment of a method **300** for performing nested speculative regions. FIG. **3** will be explained with reference to FIG. **2**. The method **300** includes responding to beginning a speculative region **304**, responding to an abort command **312**, and responding to a commit command **320**.

The method **300** may begin with in response to beginning a speculative region **304**. For example, FIG. **2** begins with speculate **201.1**. The method **300** continues with is speculative region nested **306**. In this case, speculate **201.1** is not nested as it has not been called by another routine **210.1**, **210.2**, **220.1**, and **220.2**. The method **300** continues with store link information to the abort handler associated with the speculative region **310**. For example, a link to the abort handler **204.1** may be stored when beginning speculative region **201.1**. The method **300** then returns to start **302**.

The method **300** may continue with in response to beginning a speculative region **304**. For example, routine A **200.1** may continue with call Routine B **202.1**. Routine B **210.1** is called and routine B begins with speculate **211.1**.

The method **300** continues with is speculative region nested **306**. In this case, speculate **211.1** is nested because it was called by routine A **200.1**, which was inside a speculative region begun with speculate **201.1**, so the method **300** continues with store link information to the abort handler associated with the previous speculative region **308**. For example, a link may be stored from abort handler **214.1** to abort handler **204.1**.

The method **300** continues with store link information to the abort handler associated with the speculative region **310**. For example, a link to the abort handler **214.1** may be stored when entering speculate **211.1**. The method **300** then returns to start **302**.

The method **300** may continue with in response to a commit command **320**. For example, routine B **210.1** may continue with commit **213.1**. The method **300** may continue with is commit nested **322**. In this case the commit **213.1** is nested, so the method **300** continues with restore link information to the abort handler associated with the previous speculative region **324**. Here, the link information to abort handler **204.1** is restored. The method **300** may continue with removing link information to the abort handler associated with the speculative region **326**. For example, link information to abort handler **214.1** may be removed.

The method **300** may continue with in response to beginning a speculative region **304**. For example, routine B **210.1** may have completed and returned control to routine A **201.1**. Routine A may next perform call routine C **202.2**. Routine C **210.2** then performs speculate **211.2**. The method **300** continues with is speculative region nested **306**. In this case, speculate **211.2** is nested because it was called by routine A **200.1**, which was inside a speculative region begun with speculate **201.1**, so the method **300** continues with store link information to the abort handler associated with the previous speculative region **308**. For example, a link may be stored from abort handler **214.2** to abort handler **204.1**.

The method **300** may continue with store link information to the abort handler associated with speculative region **310**. For example, link information may be stored abort handler **214.2**. The method **300** then returns to start **302**.

The method **300** may continue with in response to beginning a speculative region **304**. For example, routine C **210.2** may continue with call Routine D **212.1**. Routine D **212.1** is called and routine D begins with speculate **221.1**. The method **300** continues with is speculative region nested **306**. In this case, speculate **221.1** is nested because it was called by routine C **210.2**, which was inside a speculative region begun with speculate **211.2**, so the method **300** continues with store link information to the abort handler associated with the previous speculative region **308**. For example, a link may be stored from abort handler **224.1** to abort handler **214.2**.

The method **300** continues with store link information to the abort handler associated with the speculative region **310**. For example, a link to the abort handler **224.1** may be stored when entering speculate **221.1**. The method **300** then returns to start **302**.

The method **300** may continue with in response to a commit command **320**. For example, routine D **220.1** may continue with commit **223.1**. The method **300** may continue with is commit nested **322**. Here it is a nested commit, so the method **300** continues with restore link information to the abort handler associated with the previous speculative region **324**. For example, link information to the abort handler **214.2** may be restored. The method **300** may continue with removing link information to the abort handler associated with the speculative region **326**. For example, link information to **224.1** may be removed.

The method **300** may continue with in response to beginning a speculative region **304**. For example, routine D **220.1** may return back to routine C **210.2**. Routine C **210.2** may continue with call Routine E **212.2**. Routine E **220.2** is called and routine E **220.2** begins with speculate **221.2**. The method **300** continues with is speculative region nested **306**. In this case, speculate **221.2** is nested because it was called by routine C **210.1**, which was inside a speculative region begun with speculate **211.2**, so the method **300** continues with store link information to the abort handler associated with the previous speculative region **308**. For example, a link **250.2** may be stored from abort handler **224.2** to abort handler **214.2**.

The method **300** continues with store link information to the abort handler associated with the speculative region **310**. For example, a link to the abort handler **224.2** may be stored when entering speculate **221.2**. The method **300** then returns to start **302**.

The method **300** may continue with in response to an abort command **320**. For example, an abort may occur because another processor may access memory that is part of the working set of memory locations of routine E **220.2**.

The method **300** may continue with run abort handler associated with the aborted speculative region **314**. For example, the aborted speculative region in FIG. **2** was the region between speculate **221.2** and commit **223.2**, so the abort handler **224.2** for this region is abort handler **224.2**. Abort handler **224.2** may be called which may reset registers and perform other types of clean-up to undo instructions in the speculative region between speculate **221.2** and commit **223.2**. The method **300** may continue with is the aborted speculative region nested **316**. For example, since routine E **220.2** was called from routine C **210.2** which had called speculate **211.2**, the speculative region is nested. The method **300** may continue with for each previous speculative region, running the abort handler of the previous speculative region **318**. For example, abort handler **214.2** associated with routine C **210.2** is the abort handler **214.2** associated with a previous speculative region. The abort handler **214.2** may be called as abort handler **224.2** may have a link **250.2** to abort handler **214.2**. Additionally, abort handler **204.1** is a previous speculative region. The abort handler **204.2** may be called as abort handler **214.2** may have a link **250.1** to abort handler **204.1**. The method **300** may return to start **302**. Routine A may attempt to execute again until an abort does not occur during the execution of routine A or one of the routines that routine A calls.

FIG. **4** schematically illustrates an example of an embodiment of an apparatus for nested speculative regions for a synchronization facility.

Illustrated in FIG. **4** is processor **102**, which includes two or more cores **602**, **604**, and memory **104**, which may be shared by the two more cores **602**, **604**.

The cores **602**, **604** include cache memory **604**, **605**, registers **606**, **607**, rSP **608**, **609**, rIP **610**, **611** , and synchronization facility **616**, **617**.

The cache memory **604**, **605** may be a place to store memory locations **104** for quick access and may include facilities for maintaining the consistency of the cache memory **604**, **605** with the memory **104**. The registers **606**, **607** may include registers **606**, **607** for storing data, locations, and flags indicating the status of events.

The rSP **608**, **609** may be a register stack pointer (rSP) with the address to a stack **632**, **633** in memory **104** for use by a currently executing routine. The rIP **610**, **613** may be a register instruction pointer (rIP) with the address to code that is to be executed next for a routine.

The synchronization facility **616**, **617** may include a saved_rIP **618**, **619**, a saved_rSP **620**, **621**, an nesting level **622**, **623**, rAX **624**, **625**, and rFLAGS **626**, **627**. The saved_rIP **618**, **619** may be the last rIP **610**, **613** before a nested speculative region was called. The saved_rSP **620**, **621** may be the last rSP **608**, **609** before a nested speculative region was called. Nesting level **622**, **623** may indicate the currently nesting level of the speculative regions. The rAX **624**, **625** may be used to copy the value of nesting level **622**, **623** and abort information when an abort occurs. The rFLAGS **626**, **627** may be set to indicate statuses of why an abort occurred as well as indicate other statuses in the system. The synchronization facility **616**, **617** may include speculate and commit commands, which may be implemented in microcode or circuits which may include registers and memory.

The memory **104** may include code with speculative region **630**, **631**, stacks **632**, **633**, code region **652**, working set **636**, **642**, synchronization facility **650**, and, optionally, current abort handler frame **648**.

The code with speculative region **630**, **631** may be code stored in the memory **104** that utilizes the synchronization facility **650** with speculate and commit commands that are executed by a core **602**, **603**. For example, the routines A, B, C, D, E, **200.1**, **210.1**, **210.2**, **220.1**, **220.2** may be speculative regions **630**, **631**. The code region **652** may be a portion of code that is executed by a core **602**, **603**. The stacks **632**, **633** may be portions of memory **104** used to execute the code with speculative region **630**, **631**. The working sets **636**, **642** may be memory locations **389**, **639**, **644**, **645** that are used inside speculative regions of the code with speculative regions **630**, **631**.

The synchronization facility mechanism **650** may be an extension of the instruction set of the processor **102** that provides a synchronization facility. The synchronization facility **650** provides for atomic modification of multiple memory locations **638**, **639**, **644**, **645** by a speculative region. Code with speculative region **630**, **631** is executed by a core **602**, **603**. A speculative region may begin with a speculate command and end with a commit command. The speculative region may access memory locations in working set **636**, **642** between the speculate and commit commands that are to be accessed atomically, which means that other regions of code should not access the memory locations **638**, **639**, **644**, **645** between when a speculative region begins with a speculate command and when a speculative region ends with a commit command. So, while the speculative region is executing, the working set **636**, **642** is only to be accessed by the speculative region. If a code region **652**, which itself may be a speculative region, attempts to access one of the memory locations of the working set **636**, **642**, before the speculative region issues a commit command, then the synchronization facility **650** aborts either the code region **652** or the code with speculative region **630**, **631**. The code with speculative region **630**, **631** may be aborted and then an attempt may be made to re-execute the code with speculative region **630**, **631**.

FIG. **5** illustrates examples of synchronization facility commands **500** speculate, nested speculate, commit, and nested commit commands. Non-nested speculate **502** may be implemented as a command that (a) stores the instruction pointer for the next instruction, (b) stores the stack pointer, and (c) adjust nesting level. For example, referring to FIG. **4**, when code with speculative region **630**, **631** is executed by a core **602**, **603** and a speculate command is executed the following may be performed. The rIP **610**, **613** may be stored in saved_rIP **618**, **619**, and rSP **608**, **609** may be stored in saved_rSP **620**, **621**, and the nesting level **622**, **623** may be set to indicate that there is no nested speculative regions, which may be represented by one. A zero in nesting level **622**, **623** may indicate that there is currently no active speculative region.

The nested speculate **504** may be implemented as a command that (a) saves the stored instruction pointer and the stored stack pointer, (b) stores the instruction pointer and stack pointer like the non-nested speculate, and adjusts the nesting level. For example, referring to FIG. **4**, nested speculate **504** may be implemented as a command that pushes saved-rSP and saved-rIP on the stack **632**, **633**; stores the rIP **610**, **613** in saved_rIP **618**, **619**, and stores rSP **608**, 609 in saved$_{13}$ rSP 620, 621; and, changes the value of nesting level 622, 623 to indicate that the nesting level 622, 623 is greater by 1.

The nested commit 506 may be implemented as a command that restores the values for the saved instruction pointer and the saved stack pointer 506, and adjusts the nesting level. For example, referring to FIG. 4, nested commit 506 may be implemented as a command that pops saved-rSP, pops saved_rIP from the stack 624, 625, and reduces the value by one of nesting level 622, 623.

The non-nested commit 508 may adjust the nesting level. For example, the core 602, 603 may set nesting level 622, 623 to indicate there is no nesting, which may be represented by zero.

FIGS. 6A and 6B schematically illustrates code with speculative regions 630 (illustrated in FIG. 4) implemented with code 400. FIGS. 6A and 6B are explained in conjunction with method 300 of FIG. 3, apparatus of FIG. 4, and examples of synchronization facility commands 500. Referring to FIGS. 6A and 6B, line numbers 430 indicate the line number 430 of the code 400. Lines that begin with "//" are comments. For example, line 410 is comments. The nesting level may be kept in the nesting level 622 register as discussed in conjunction with FIG. 4. The code 400 may be executed by core 602. The code 400 is stored in memory 104 in speculative region 630. The nesting level 622 is initialed to 0 prior to the execution of code 400 so that at 310, the nesting level will be 0,so the nesting level indicates that the speculate region 402 is not a nested speculate region.

Referring back to FIG. 3, the method 300 begins with in response to beginning a speculate region 304. For example, the code 400 begins with line 401 which is a label "Retry:," and a convenient way for another line to refer to line 401. The code 400 then proceeds with a speculate region at line 402 with speculate.

The method 300 continues with is speculative region nested 306. For example, continuing with the example of FIGS. 6A and 6B, the synchronization facility 616 may determine as part of the speculate 402 command that speculate 402 is not nested based on the value in nesting level 622. The core 602 may set nesting level 622 to one to indicate the level of the speculate region, and set rAX 624 to zero to indicate to the application that there has not yet been an abort.

The method 300 continues with store link information to the abort handler associated with the speculative region 310. As part of the speculate command, the core 602 may store the instruction pointer rIP 610 in the location saved_rIP 618.

Additionally, as part of performing the speculate 402, the core 602 may store whether or not an abort has occurred in a location rFLAGS 626. The synchronization facility 616 on an abort will set rAX 624 to a non-zero value to include the nesting level 622 and abort information, set rFLAGS 626 to indicate an abort occurred, and restore the rIP 618 to "JNZ abort_handler" 403 so that on an abort, the core 602 will jump to line 409: "Abort_handler", since "JNZ abort_handler" 403 will jump to abort_handler 409, if rFLAGS 626 is not zero.

If there is an abort during the execution of the speculative region (after speculate 402 and before commit 407), and not during a nested speculative region, then the synchronization facility 616 will copy saved_rIP 618 into rIP 610. The code line 403, "JNZ Abort_Handler", will then be executed and since JNZ will be true, because rFLAGS 626 is not zero, execution will jump to code line 409, Abort_handler. Thus, store link information to the abort handler associated with the speculative region 306 is performed.

As part of performing the speculate 402, as discussed in conjunction with FIGS. 4 and 5, the core 202.1 may store the stack pointer rSP 608 in location saved_rSP 620 The saved_rSP 620 may be used to restore the stack pointer rSP 608 if the current speculate region 402 is aborted. The stack pointer rSP 608 points to a location in the stack 624 which is a portion of memory 104 that is being used by the speculate region 620.

The method 300 may then continue with in response to entering a speculate region 304. For example, continuing with the example in FIG. 6, the core 602 may access memory location 638, 639, 644, 645. Memory location 638, 639, 644, 645 250 may be memory location 638 which is part of working set 636 of FIG. 4. Then the core 602 may execute nested speculate 405, which refers to label nested speculate 451 of FIG. 6B. The code 400 may continue with speculate 452, which enters a speculative region.

The method 300 may continue with is speculative region nested 306. As part of performing the speculative command 452, nesting level 622 is used to determine whether the speculate 452 is nested. When speculate 402 was executed, nesting level 622 was incremented to 1, so the nesting level is 1 and does indicate the speculate 452 is nested. The core 602 increments nesting level 622 by 1 so that nesting level 622 is now 2.

The method 300 may continue with store link information to the abort handler associated with the previous speculative region 308. For example, as part of performing the speculate 452, the core 602 may push the saved_rIP 618 and the saved_rSP 620 on the stack 624, which may increment the stack pointer 624, rSP 608.

The method 300 may continue with store link information to the abort handler associated with the speculative region 310. For example, as part of performing the speculate 452, the core 602 may store the instruction point rIP 638 in the location saved_rIP 618. The core 602 may store the stack pointer rSP 608 in location Saved_rSP 620. The saved_rSP 620 may be used to restore the stack pointer rSP 608 if the current speculate region 402 is aborted. The method 300 continues with returning to start 302.

The method 300 may continue with in response to entering a commit command 306. For example, continuing with the example of FIG. 6, the core 602 may execute the instructions associated with access memory locations 644, 645. For example, the core 602 may access memory location 644 of working set 642. The core 602 may then execute commit 455.

The method 300 may continue with is commit nested 322. For example, continuing with the example of FIG. 6, nesting level 622 is 2, so this indicates that the commit is a nested commit as nesting level 622 is greater than 1.

The method 300 may continue with restore link information to the abort handler associated with the previous speculative region 324. For example, continuing with the example of FIG. 6, the core 602 may retrieve the saved_rIP 618 and saved_rSP 620 from the stack 632 that were stored on the stack 632, and place the retrieved saved_rIP 618 into the saved_rIP 618, and place the retrieved saved_rSP 620 into the saved_rSP 620. The core 602 may decrease the nesting level indicated by nesting level 622 by 1.

The method 300 may continue with removing link information to the abort handler associated with the corresponding speculative region 322. For example, continuing with the example of FIG. 6, the link information to the abort handler associated with the speculate 452 may have been removed by the core 602 retrieving the saved_rIP 618 from the stack 624 and putting it in saved_rIP 618.

The method **300** may continue with returning to start **302**. The method **300** may continue with in response to entering a commit command **306**. For example, continuing with the example of FIG. **6**, the core **602** may execute the instructions associated with access memory locations **638**, **639** at line **406**. For example, memory location **638**, **639** may be memory location **638** and memory location **639** of working set **636**. The core **602** may then execute commit **407**.

The method **300** continues with is the nesting level nested **306**. For example, continuing with the example of FIG. **6**, nesting level **622** is 1, so this indicates that the commit is not a nested commit as nesting level **622** is not greater than 1. As part of performing commit **407**, the core **602** may set nesting level **622** to 0. And, the core **602** may decrement rSP **608** by two locations to put rSP **608** back to where it was prior to the speculate **402**.

The method **300** continues with stop. For example, continuing with the example of FIG. **6**, the core **602** may continue to execute the code in **630**, but since there are no pending speculative regions the synchronization facility **616** may not be used again.

Alternatively to the code **400** example above, the method **300** may continue with in response to an abort command **312**. For example, in the example of FIG. **6**, when the code **630** is in speculative region, lines **402** through **407**, another speculative region **631** or code region **652** may access the memory locations **638**, **639**, or when the code **630** is in speculative region, lines **452** through **455**, for the inner speculative region, another speculative region **631** or code region **652** may access the memory locations **644**, **645**. The synchronization facility **650** may then abort the speculative region, lines **402** through **407**, or the inner speculative region, lines **452** through **455**.

The method **300** continues run abort handler associated with the aborted speculative region **314**. For example, continuing with the example of FIG. **6**, the core **602** may be executing instructions at line **404**, when the synchronization facility **650** determines to abort the speculative region **630**, which corresponds to the code lines **402** through **407** and may include codes lines **409** through **424**. The rIP **610** is then set to saved_rIP **618**, which in this case would be line **403**, "JNZ Abort_Handler." For example, continuing with the example of FIG. **6**, the core **602** would execute line **403** "JNZ Abort_Handler" and since rFLAGS **626** is not zero, the core **602** would jump to line **409**. And, then as indicated in the comments of lines **410-413**, the core **602** may clean up non speculative portions of memory and registers as well as keep statistics regarding the number of aborts of the speculative region **620**.

The method **300** may continue is aborted speculative region nested **316**. For example, continuing with the example of FIG. **6**, the core **602** may execute line **414** which tests whether or not the rAX **624** register indicates that there is nesting or not, since the value of the nesting level **252.1** is copied into rAX **624** when an abort occurs. In this example, the rAX **624** would indicate that there is not nesting, so the core **602** would execute line **422** "JZ Done," and the results of the test in line **414** are 0, then the core **602** next executes line **423**. The example may continue with "JMP Retry" line **424** which would bring the core **602** back to line **401** to retry the speculative region **402** through **407**.

Alternatively to the code **400** example above, the method **300** may continue with in response to an abort command **312**, where the abort occurs in the nested speculative region of lines **452** through **455**. For example, in the example of FIG. **6**, when the code **630** is in nested speculative region, lines **452** through **455**, another speculative region **631** or code region **652** may access the memory locations **644**, **645**. The synchronization facility **650** may then abort the nested speculative region, lines **452** through **455**.

The method **300** continues run abort handler associated with the aborted speculative region **314**. For example, continuing with the example of FIG. **6**, the core **602** may be executing instructions at line **454**, when the synchronization facility **616** determines to abort the speculative region **631**. The rIP **610** is then set to saved_rIP **618**, which in this case would be line **453**, "JNZ Nested_Abort." And, in an abort, nesting depth **622** and abort information is put into rAX **624** and rFLAGS **626** is set according to values in rAX **624**. For example, continuing with the example of FIG. **6**, the core **602** would execute line **453** "JNZ Nested Abort" and since rFLAGS **626** is not zero, the core **602** would jump to line **457**. And, then as indicated in the comments of lines **458-461**, the core **602** may clean up non speculative portions of memory and registers as well as keep statistics regarding the number of aborts of the speculative region **620**.

The method **300** may continue is aborted speculative region nested **316**. For example, continuing with the example of FIG. **6**, the core **602** may execute line **462** which tests whether or not the rAX **624** register indicates that there is nesting or not. In this example, the rAX **624** would indicate that there is nesting as rAX **624** would be 2,so the core **602** would execute line **465**, which subtracts 1from rAX **624**. The core **602** would then execute lines **466** through **468**. Line "POP rDI" **466**, takes the saved_rIP **618** previously stored on the stack **632** and puts it in a temporary place rDI. Line "POP rSP" **467** takes the previously stored saved_rSP **620** and puts it in rSP **608**, which was the stack pointer to the speculative region **402** through **407**. The core **602** then executes "JMP [rDI]" **468**, which transfer control to line **403** "JNZ Abort_Handler".

For each previous speculative region, running the abort handler of the previous speculative region **318**. Continuing the example of FIG. **6**, there is only one more abort handler to run and that is the abort handler for speculative region **402** through **407**. Continuing with the example above, as disclosed above, the core **602** executing line "JNZ Abort_Handler" **403** after an abort would run the abort handler for the speculative region **402** through **407**.

The method **300** would then continue with returning to start **302**. The core **602** would then jump to line **401** "Retry" and attempt to execute the speculative region **402** through **407** again.

FIG. **7** illustrates an example of a synchronization facility for nested speculative regions. Illustrated in FIG. **7** is abort handler frames **702** and current abort handler frame **648**.

The abort handler frame **702** includes abort handler pointer **704**, continuation information **706**, level **708**, and next abort handler **710**. Code with speculative region **630** includes code that creates the abort handler frame **702** in the stack before a speculate instruction.

The abort handler pointer **704** is a pointer to an abort handler for the current speculative region **630**. Continuation information **706** is register state including the stack pointer to revert to for the abort handler. Level **708** is a level of nesting of the speculative region **630**. Next abort handler **710** is a pointer to a previous abort handler frame **702**.

The current abort handler frame **264** (see also FIG. **4**) points to the current abort handler frame **702**. Before entering a new speculative region in code with speculative region **631**, the abort handler frame **702.2** is created on the stack **633**, and populated with the required information, and then chained to the old current_AH_frame **702.1**, if the speculative region **630** is a nested speculative region. Current abort handler frame **648** is updated to point to the current abort handler frame **702.2**.

On an abort, the abort handler frames **702** are traversed by a routine that calls each of the abort handlers for each abort handler frame **702** by using the abort handler pointer **704** and linking to the previous abort handler frame **702** using next abort handler **710**. The routine may check to level **708** of the abort handler frame **702**, and if the level **708** is greater than a level of nesting indicated by a nesting counter, then the routine will not call the abort handler associated with the abort handler frame **702**. Thus, the method **300** may be performed using abort handler frames **702**.

Examples of disclosed embodiments of the synchronization facilities provide the advantage that nesting is supported such that multiple speculative regions can be contained within another speculative region, which allows speculative regions to call functions that themselves use the synchronization facility.

Examples of disclosed embodiments of the methods, apparatus, and computer readable medium for nested speculative regions have the advantage of calling nested abort handlers whereas current synchronization facilities only notify the outermost speculative region of an abort, thus ignoring abort handlers registered by nested speculative regions, which may clean up memory locations and registers, and may keep statistics on the number of aborts. The omission of calling abort handlers of nested speculative regions means that nested code must not rely on the abort handler ever being called in case of an abort. This will restrict what the code in nested speculative regions can do. For example, the nested code cannot use the abort handlers to do clean-up of non-speculative modifications it has done inside the speculative region.

Examples of disclosed embodiments of the methods, apparatus, and computer readable medium for nested speculative regions have the advantage of calling nested abort handlers whereas current, so that statistics of success-abort rates to determine future behavior can be calculated.

The methods or flow charts provided herein may be implemented in a computer program, software, or firmware incorporated in a computer-readable storage medium for execution by a general purpose computer or a processor. Examples of computer-readable storage mediums include a read only memory (ROM), a random access memory (RAM), a register, cache memory, semiconductor memory devices, magnetic media such as internal hard disks and removable disks, magneto-optical media, and optical media such as CD-ROM disks, and digital versatile disks (DVDs). The computer-readable storage may be non-transitory.

What is claimed is:

1. A method of performing an abort of a speculative region of code in nested speculative regions of code, the method comprising:

in response to entering a nested speculative region of code, storing link information to an abort handler associated with a previous speculative region of code, wherein the link information is used by an abort handler associated with the nested speculative region of code to link the abort handler associated with the nested speculative region of code with the abort handler associated with the previous speculative region of code; and

in response to a commit command, removing link information from the abort handler.

2. The method of claim **1**, wherein when the commit command is nested, the method further comprises restoring link information to the abort handler associated with the previous speculative region of code.

3. The method of claim **1**, wherein in response to an abort command, the method further comprises running the abort handler associated with the aborted speculative region of code.

4. The method of claim **3**, wherein the method further comprises for each previous speculative region of code, running an abort handler associated with each previous speculative region of code.

5. The method of claim **3**, wherein running the abort handler associated with the aborted speculative region of code, further comprises:

transferring program control to a location in a saved instruction pointer register.

6. The method of claim **5**, wherein for each previous speculative region of code, running the abort handler of each previous speculative region of code, further comprises:

retrieving a saved instruction pointer from a stack, and running the abort handler of each previous speculative region of code by transferring program control to a second location in the retrieved saved instruction pointer.

7. The method of claim **3**, wherein running the abort handler associated with the aborted speculative region of code, further comprises:

transferring program control to an abort handler pointed to by a current abort handler frame, wherein the current abort handler frame is stored in a thread local memory.

8. The method of claim **1**, further comprising:

accessing memory locations of a working set; and, wherein a second core accessing the memory locations of the working set triggers the abort command.

9. The method of claim **1**, further comprising:

incrementing a nesting level in response to each speculate command and decrementing the nesting level in response to each commit command.

10. The method of claim **1**, wherein in response to entering the speculative region of code, comprises:

allocating memory for an abort handler frame;

storing link information to an abort handler associated with the previous speculative region of code in the abort handler frame;

storing a level in the abort handler frame; and

storing link information to an abort handler associated with the previous speculative region of code in the abort handler frame.

11. The method of claim **10**, wherein in response to an abort command, comprises:

retrieving a current abort handler frame;

if the level of the abort handler frame is not greater than a current nested level, then running the abort handler associated with the aborted speculative region of code by running the abort handler associated with the abort handler frame;

if the aborted speculative region of code is nested, then for each previous speculative region of code, running the abort handler of the previous speculative region of code by setting the current abort handler frame to the next abort handler of the current abort handler frame, and running the abort handler associated with the abort handler frame.

12. The method of claim **1**, wherein storing link information to an abort handler associated with the speculative region of code, further comprises: storing an instruction pointer to a saved instruction pointer register.

13. The method of claim **1**, wherein storing link information to an abort handler associated with the previous speculative region of code, further comprises:

storing an instruction pointer to an abort handler frame created in a stack.

* * * * *